Catena 172 (2019) 581–589

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Direct and indirect impacts of ionic components of saline water on irrigated soil chemical and microbial processes

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ARTICLE INFO

Keywords:
Saline water
Salt ions
Sodic soil
Organic carbon
Microbial activity

ABSTRACT

The characteristics of ions in irrigation water can be significantly different in response to the changes in the salinity gradient. The chemical and biological processes of soils which were irrigated with this kind of water would therefore, be remarkably influenced. Based on the field sampling data and utilizing the Structural Equation Model (SEM), this paper aims to investigate the ionic characteristics of irrigation water and evaluate their direct and indirect impacts on soil salt ions, nutrients and microbial metabolic activities. The present results demonstrated that the ionic components of irrigation water had a direct influence on the soil salt ions. In particular, the Na^+ concentrations in irrigation water were not only seen to significantly increase the soil Na^+ concentrations but also change the other soil ions' concentrations. The contents of soil total nitrogen (TN), available phosphorus (P_{ava}) and available potassium (K_{ava}) appeared to change slightly with the increase of water salinity and meanwhile, no significant impact was found from any of the ions present in the irrigation water. Although high concentrations of Na^+, Cl^-, SO_4^{2-}, Mg^{2+} and Ca^{2+} in irrigation water significantly drove the reduction of the soil organic carbon (OC), the direct influences were actually relatively small in this respect, and it was the increase of soil salt ions that dominantly led this reduction. Irrigation water with high salinity contents could significantly restrain the soil microbial metabolic activities. In addition, high concentrations of SO_4^{2-}, Mg^{2+}, Cl^-, Ca^{2+} and Na^+ in irrigation water (accounting for about 11% of the total effects), increased concentrations of soil salt ions (i.e., 74%) and reduced contents of soil OC (i.e., 15%) all contributed to this restraint, which together were seen to affect the microbial processes under saline water irrigation. The present results revealed that the ionic effects of irrigation water on soil processes would be more complex than we currently understood, which should attract increasing concerns in the future.

1. Introduction

Saline water irrigation has become an important agricultural practice worldwide due to a growing freshwater shortage which has motivated farmers to seek new water resources without good quality (Rozema and Flowers, 2008). However, saline water contains solutes of varying concentrations, and its utilization may noticeably affect soil characteristics. Actually, increasing soil salt accumulation in the rooting zone due to saline water irrigation has been a critical problem which would challenge global agricultural sustainability and food security (Ould Ahmed et al., 2007). All over the world, soil salinity causes land degradation in over 100 countries (Yan and Marschner, 2013). In Australia, about 30% of the land area affected by different types of salinization (Rengasamy 2006). Through the past eight to nine decades, a great deal of information has been achieved, which has promoted the understanding of the change in soil environment under saline water irrigation and helped to develop the technology for coping with the soil salinity problems (Letey et al., 1985; Ould Ahmed et al., 2007; Niu and Cabrera, 2010; Li et al., 2017). However, although much is known, there are still many aspects are obscure and misunderstood and many mechanisms which may be yet to be detected.

The natural characteristics of saline water are likely to vary across

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https://doi.org/10.1016/j.catena.2018.09.030
Received 27 May 2018; Received in revised form 11 September 2018; Accepted 15 September 2018
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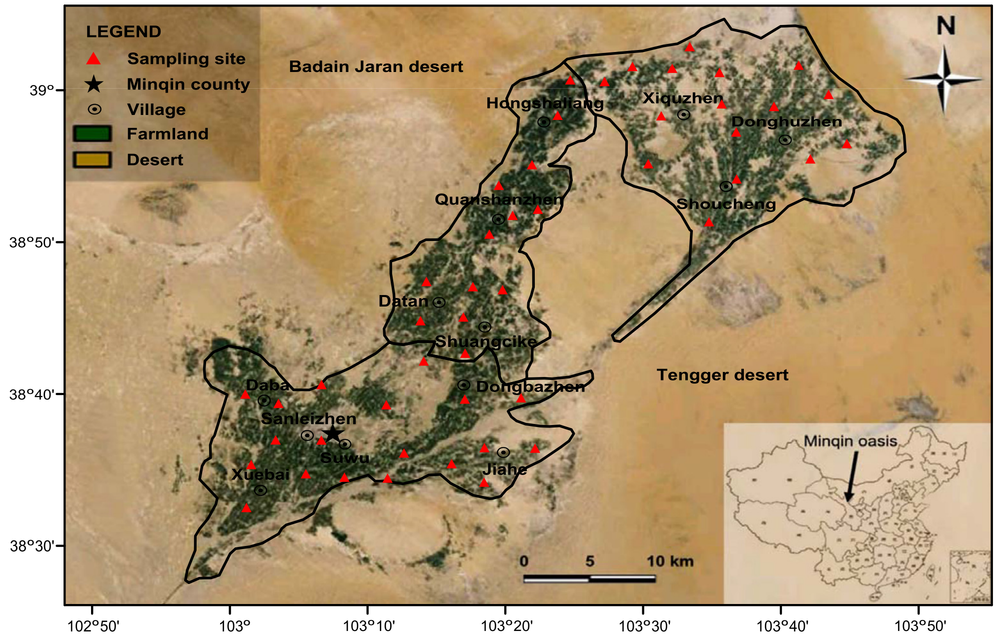

Fig. 1. Location of the sampling sites in Minqin oasis.

different regions or even locations. The chemical compositions of this kind of water would also differ throughout the world (Piper, 1944). Especially, even under the same salinity levels, different ionic components are generally a visible characteristic of saline water. In addition, certain correlations among saline water ions may vary as soon as the water become saline (Mondal et al., 2010). The chemical interactions between the active components (e.g., Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-} and SO_4^{2-}) might also change significantly. Under this circumstance, some other properties of water (such as dissolving capacities) would be influenced and consequently, affect the performance of soils that are irrigated. Considering this issue, the significant research efforts are needed to better understand the influences of high concentrations of dissolved solids and the complex chemical compositions of saline irrigation water on soil processes, which may be important for revealing the mechanism of soil ecosystem response to saline stress, and thus, be useful in the management of this kind of water resources and control the potential impacts on soils.

Previously, numerous studies have dealt with the influences of saline water irrigation on various aspects of soil characteristics. Chiefly, the application of saline water is likely to change the soil aggregate structure, reduce the permeability, increase the salinity and restrict the water, nutrients and oxygen availability (Russo, 2005; Wong et al., 2008). However, a large number of these researches merely considered the influences of the different water salinity levels (generally in the form of electrical conductivity) instead of the different water chemical components. Some studies have used NaCl as the sole salinizing agent to evaluate these effects. However, Boyko (1966) found that a balance between the different species of ions may be less toxic than the equimolar concentrations of single salt, and that the simulation of saline water irrigation with a single salt may result in misleading and erroneous interpretations about the soil environment variation under saline conditions. Therefore, important attention should be given to the responses of soil ecosystems to the irrigation water with different ionic components. On the other hand, many previous findings were relatively independent, i.e., they only investigated one particular aspect of the soil properties' changes under the condition of the saline water irrigation (Chen et al., 2010; Ahmed et al., 2012; Abegunrin et al., 2016). Since the soil system is dynamic, which contains a large number of physicochemical and biological processes, how to distinguish the direct and indirect influences of the ionic components of saline irrigation water on these processes, as well as to explore their inter-relationships are extremely important.

With this view in mind, we collected water and soil samples from a typical saline water irrigated oasis, analyzed the ionic compositions of irrigation water, investigated their effects on the soil salt ions, nutrients and microbial metabolic activities, and finally, discussed their interrelationships. By doing these, we hope to find out the mechanism of the water ionic components influences on the soil's chemical and microbial processes and thereafter, to contribute to the science of saline water management and soil quality improvement.

2. Materials and methods

2.1. Study area description and sampling

The study area, Minqin oasis (103°00′ to 103°50′ E, 38°30′ to 39°05′N), is located in the lower reaches of the Shiyang River, northwest China. It is an ideal region for investigating the influences of long-term saline water irrigation on the soil environment. As one of the most ecologically fragile regions in China, the surface water used for irrigation in Minqin Oasis is very limited and therefore, plenty of the irrigation water comes from the underground reserves (You et al., 2011). The groundwater salinity ranges in this oasis from about 0.23 to 15.05 $dS\ m^{-1}$, a value that is relatively high because of the 60 years of water exploitation for the purpose of irrigation (Edmunds et al., 2006). In addition, the groundwater components have also changed a lot over the past few centuries due to the influence of climate change and numerous agricultural operations (Zhu et al., 2007; Hao et al., 2017).

A detailed illustration of the sampling has been reported in a previous study of Chen et al. (2016). In a brief way, a total of 48 irrigation groundwater wells were selected for the water sampling during April to August 2014 in this oasis (Fig. 1). After a period of about 30 min intensive pumping, each water sample was taken and then sealed and transferred to the Key Laboratory of Ecohydrology of Inland River Basin at the Chinese Academy of Sciences (CAS) for further chemical analysis.

Within the period of August 21–28, totally 48 farmlands, which were irrigated by the groundwater wells sampled in this study, were selected for the soil sampling. From each farmland, a total of 13 soil samples (followed as an *S*-shaped curve) over a depth of 0–20 cm were collected and then mixed as one composite sample. All of the soil

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